

REACTIONS OF THE JAPANESE BEETLE TO SPRAY
DEPOSITS ON FOLIAGEBy E. R. VAN LEEUWEN, *Associate Entomologist, Division of Japanese and Asiatic Beetle Research, Bureau of Entomology*

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INTRODUCTION

Japanese beetles are not so abundant on foliage sprayed with lead arsenate as they are on unsprayed foliage, upon which they frequently accumulate. In view of the toxicity of lead arsenate to certain leaf-eating insects of this type, one would hardly expect to find so many beetles on poisoned as on unpoisoned plants. Nevertheless, the great difference between the number of beetles observed on the sprayed plants and on the unsprayed plants, under similar conditions, and the lack of any great number of dead beetles about the poisoned plant would seem to be sufficient reasons for believing that the spray has a repellent effect on the beetles. Lead arsenate and other arsenicals high in toxicity have therefore been considered by certain investigators as more repellent than toxic to the beetle.

From the results of earlier investigators Davis¹ concluded that both the paste and the powdered lead arsenates were primarily repellents, and not actually remedies, since they did not destroy the beetle. Hadley² supported this conclusion by referring to lead arsenate as

¹ DAVIS, J. J. THE GREEN JAPANESE BEETLE. N. J. Dept. Agr. Circ. 30, 33 p., illus. 1920.² HADLEY, C. H. THE JAPANESE BEETLE. N. J. Dept. Agr. Circ. 46, 20 p., illus. 1922.

being effective, not as a killing agent but as a repellent. B. R. Leach and F. J. Brinley, formerly of the Japanese beetle laboratory, stated (in unpublished notes) that the reaction of the beetle to spray deposits of standard pastes and powders of arsenates and arsenites and of other miscellaneous materials, including lime, was substantially the same in all cases, regardless of whether the spray was or was not arsenical. Leach and Brinley also noted that the feeding of the beetle on spray deposits of ferrous arsenate depended on the physical character of the deposits. When the spray mixture was made from freshly prepared and undried ferrous arsenate, the deposit was smooth, shiny, and amorphous; but when the spray mixture was made from dry, powdered ferrous arsenate, the deposit was granular and gritty and stood out prominently on the leaf. The beetles ate the former deposit readily, but refused to eat the latter. In 1921 Moore³ concluded that Japanese beetles are not repelled from sprayed foliage by the color, physical condition, or taste of the arsenical, but that they appear to be repelled by the toxic symptoms resulting from eating some of the arsenical.

The foregoing review of the literature indicates that a study of the feeding habits of the beetle with relation to foliage on which there are spray deposits constitutes a fundamental problem. Accordingly, the writer, assisted by W. A. Price in 1923 and by O. G. Anderson in 1924 and 1925, carried out a series of experiments to determine why the Japanese beetle will not readily eat standard spray materials. This was considered to be necessary before undertaking the next phase of the problem—namely, the preparation of a poisonous spray that the beetle will eat readily. The lead arsenate used in all the experiments was ordinary acid lead arsenate unless otherwise mentioned. The term "check" refers in each case to unsprayed or untreated foliage or to foliage sprayed with water only.

ATTRACTIVE INFLUENCE OF AN ACCUMULATION OF BEETLES

It has been noted repeatedly by various workers that the Japanese beetle is a gregarious insect. To determine the attractiveness of an accumulation of Japanese beetles on a tree to other Japanese beetles in the vicinity, at the beginning and ending of a given period of time counts were made of the number of individuals on a plant kept comparatively free of beetles, and of the number coming to a similar plant upon which they were allowed to congregate. All observations were made in the field. The conditions under which the two plants were growing, beetle abundance, and many other factors involved were, comparatively speaking, the same, the only difference being that on one plant all beetles were counted and removed at the end of short intervals, whereas on the other plant the beetles were allowed to accumulate during the entire period of observation. (Table 1.)

³ MOORE, W. THE REACTION OF THE JAPANESE BEETLE TO ARSENICAL SPRAY DEPOSITS. Jour. Econ. Ent. 15: 67-71, 1922.

TABLE 1.—*Attractive influence upon Japanese beetles of an accumulation of these beetles*

Plant	Date	Time of day	Beetles coming to a plant from which—		Excess of beetles on undisturbed plant	Beetles coming to plant from which beetles were removed, based on number coming to undisturbed plant
			Beetles were re-removed	Beetles were not re-removed		
	1923		Number	Number	Number	Per cent
Raspberry.....	July 6	10 a. m.	50	79	29	63.3
Do.....	do	10 to 11 a. m.	42	96	54	43.8
Peach.....	do	1 to 2 p. m.	200	257	57	77.8
Do.....	do	2 to 3 p. m.	100	153	53	65.4
Do.....	July 7	10 to 11 a. m.	89	117	28	76.1
Do.....	do	11 to 11.30 a. m.	39	55	16	70.9
Do.....	do	1.30 to 2.30 p. m.	31	48	17	64.6
Smartweed.....	July 12	11 a. m. to 12 m.	51	172	121	29.7
Do.....	do	1 to 2 p. m.	40	156	116	25.6
Do.....	do	2 to 3 p. m.	2	7	5	28.6
Total or average.....			644	1,140	496	56.5

The data in Table 1 indicate that more beetles alight on a plant on which beetles are allowed to accumulate than on a plant from which all the beetles are removed as they arrive. Considering the number alighting on the undisturbed plant as normal, the number of beetles alighting on the disturbed plant was 56.5 per cent of normal.

REPELLENCY OF LEAD ARSENATE TO BEETLES

NUMBER OF BEETLES ALIGHTING ON SPRAYED AND UNSPRAYED FOLIAGE

A test was made in which one patch of smartweed was sprayed with 4 pounds of lead arsenate to 50 gallons of water and another was left unsprayed. The beetles were removed from both patches as they alighted, thereby removing any influence which an accumulation of beetles might exert in attracting others. Table 2 gives the results of several observations of the number of beetles alighting on two patches of smartweed between 10 and 11.42 a. m.

TABLE 2.—*Number of Japanese beetles alighting on sprayed and unsprayed foliage*

Date	Beetles alighting on—		Excess of beetles on unsprayed plant	Beetles alighting on sprayed foliage based on number coming to unsprayed foliage
	Sprayed plant	Un-sprayed plant		
1925	Number	Number	Number	Per cent
July 5.....	73	110	37	66.4
July 6.....	73	144	71	50.7
July 7.....	85	111	26	76.6
July 8.....	37	52	15	71.2
July 9.....	104	105	1	99.0
Total or average.....	372	522	150	71.3

The average number of beetles alighting on the sprayed foliage was 71.3 per cent of the number alighting on the unsprayed foliage. The results indicate that beetles are repelled from the sprayed foliage before coming into actual contact with it, if we assume that other conditions were similar in both patches of smartweed.

MOVEMENT OF BEETLES AWAY FROM FOLIAGE SPRAYED WITH LEAD ARSENATE AND FROM FOLIAGE SPRAYED WITH WATER ONLY

To obtain comparable effects of various foliage treatments on the beetles, two large cages were used and similar conditions were maintained in both cages. An apple tree infested with 696 beetles was caged and sprayed with lead arsenate 3 to 50. A similar apple tree, with a population of 890 beetles, was caged and sprayed with water only. The beetles leaving the trees were collected at intervals of 15 minutes. The experiment was conducted on August 16 and 17, 1923.

During the first hour after the lead arsenate spray was applied 62.36 per cent of the beetles had left the tree as compared with 41.69 per cent which had left the unpoisoned foliage. The percentage of beetles leaving the poisoned foliage during the second hour was 17.1, while 5.2 per cent left the unpoisoned foliage. By the end of the third hour the percentage of beetles that had left the poisoned foliage was 85.2, whereas the percentage that had left the unpoisoned foliage was only 48.3, indicating that the lead arsenate was repellent to them.

MOVEMENT OF BEETLES AWAY FROM FOLIAGE SPRAYED WITH LEAD ARSENATE AND FROM FOLIAGE SPRAYED WITH SLAKED LIME

Data were obtained on the movement of beetles away from a tree sprayed with lead arsenate, 3 pounds to 50 gallons of water, and from one sprayed with the milk from 4 pounds of stone lime to 50 gallons of water. The experiment was conducted on August 23 and 24, 1923. A total of 762 beetles were taken from the tree sprayed with lead arsenate, whereas only 641 beetles were collected from the tree sprayed with lime.

Of the 762 beetles collected from the trees sprayed with lead arsenate, 33.2 per cent left during the first hour, 10.9 per cent during the second hour, and 10.9 per cent during the third hour. The total percentage leaving during the first three hours after spraying was 55.

Of the 641 beetles on the tree sprayed with milk of lime, 31.5 per cent left during the first hour, 16.3 per cent during the second hour, and 15.1 per cent during the third hour. The percentage leaving during the first three hours after spraying was 61.9. A slightly larger percentage of beetles left the tree sprayed with milk of lime than left the tree sprayed with lead arsenate during the same period of time. In both cases, however, the majority of the beetles had left the trees within the first three hours.

MOVEMENT OF BEETLES AWAY FROM FOLIAGE SPRAYED WITH 3 AND WITH 4 POUNDS OF LEAD ARSENATE TO 50 GALLONS OF WATER

It was observed in the earlier experiments that the mechanical operation of spraying caused an average of from 12.2 to 29.3 per cent of the beetles on the tree to leave. To avoid the influence that this disturbance might have upon the migration of the remaining beetles, an experiment was conducted on August 20, 1923, in which the beetles were placed upon the foliage as soon as it had dried after spraying. Two small apple trees were caged for this experiment. One was

sprayed with 3 pounds and the other with 4 pounds of lead arsenate to 50 gallons of water. In all, 770 beetles were removed from the tree sprayed with 3 pounds of lead arsenate to 50 gallons, whereas 1,391 beetles were collected from the tree sprayed with 4 pounds of lead arsenate to 50 gallons of water.

Very little difference was noted in the number of beetles leaving the two trees. During the first hour the percentage leaving the tree sprayed with the 3-pound mixture was 12.5, while the percentage leaving the tree sprayed with the 4-pound mixture was 12.2. During the following two hours 64.5 per cent left the tree sprayed with the 3-pound mixture, whereas 64.8 per cent left the tree sprayed with the 4-pound mixture. As in other experiments of this nature, the majority (77 per cent in each case) of the beetles had left both trees by the end of the third hour. This indicates that the mechanical operation of spraying has little influence in causing the remaining beetles to leave the foliage, and that the presence of the spray residue on the foliage is the primary cause.

MOVEMENT OF BEETLES AWAY FROM TREES SPRAYED WITH LEAD ARSENATE, WITH SLAKED LIME, WITH WATER ONLY, AND FROM TREES DUSTED WITH LEAD ARSENATE

To determine the percentage of beetles leaving sprayed and unsprayed foliage, a large cage, 20 by 20 by 20 feet, was made of galvanized wire with a mesh just small enough to prevent the escape of the beetles. Because the beetles are less easily disturbed during the cool portion of the day than during the warmer periods, the cage was placed about the tree and the tree sprayed between 7 and 9 a. m. In all the tests reported in Table 3 there were thorough applications of a spray, except where lead arsenate was used in the form of a dust blown directly upon the tree with a small duster after the tree had been sprayed with water. Immediately after spraying or dusting, and after a period of one hour or so, the beetles were gathered from the floor, sides, and top of the cage. The results from several tests of this nature (which are not comparable one with another) are given in Table 3.

Treatment	Percentage of beetles leaving	
	1st hour	2nd hour
Lead arsenate spray	12.5	64.5
Lead arsenate dust	12.2	64.8
Slaked lime spray	12.5	64.5
Slaked lime dust	12.2	64.8
Water spray	12.5	64.5
Water dust	12.2	64.8

TABLE 3.—*Movement of Japanese beetles away from caged trees sprayed with lead arsenate, with slaked lime, with water only, and from trees dusted with lead arsenate*

Date	Time of application	Material used per 50 gallons of water	Beetles leaving during spraying	Beetles leaving sprayed foliage within—							Beetles shaken from tree			Total beetles		
				1 hour	2 hours	3 hours	4 hours	4½ hours	5½ hours	6½ hours	7½ hours	Hours after spraying				
				Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Number		Per cent	Number
July	9 10 a. m.	Lead arsenate, 3 pounds	15.2	20.4	39.9	74.3					95.3		6½	135	4.7	2,858
	10 11.30 a. m.	do	20.6	60.2	70.9								4½	73	6.6	1,113
	10 do	Slaked lime, 4 pounds	29.3	40.0	61.7								4½	547	23.6	2,314
	11 8.45 a. m.	Lead arsenate dust		3.6									6½	406	7.4	5,486
	12 9.30 a. m.	do	13.3	16.4	34.4	86.3					92.6		4½	27	2.3	1,189
	13 9.30 a. m.	do	3.9	22.2	75.8	97.8							4½	767	36.0	2,131
	17 10.15 a. m.	Water only	12.2	15.8	39.5	96.4							7½	921	32.3	2,850
	19 9.30 a. m.	Lead arsenate, 3 pounds	9.6		18.1	70.4					88.0		5½	163	12.0	1,355
	20 do	do	13.5		43.6								6½	69	4.4	1,555
	23 10.45 a. m.	do	15.5		44.5								4	319	31.2	1,023
Aug.	24 1.30 p. m.	do	25.8	84.7	99.1				68.8				2	14	.9	1,554
	2 10 a. m.	Lead arsenate, 4 pounds	23.3	66.6		91.6							3	109	8.4	1,303
	2 10.45 a. m.	Lead arsenate, 3 pounds	36.7			77.1							3	329	23.2	1,420
	7 10 a. m.	do	3.2	22.2		62.2					75.7		6½	138	24.3	1,668
	7 do	Lead arsenate, 4 pounds	17.9			90.2							3	80	9.8	817
	13 do	do	13.0	72.4		93.6							3	52	6.4	516
	14 9.30 a. m.	Lead arsenate, 3 pounds	9.0		37.1	92.3							3	59	7.6	772
15 10 a. m.	do	40.4	81.7	97.9								3	17	2.1	802	

The records show that the proportion of beetles leaving the foliage during spraying is rather large. The largest percentage of beetles left during the first three hours after spraying or dusting, except in the test in which water alone was used, as is shown by the following average percentages of beetles leaving within three hours after the different treatments:

	Per cent
Lead arsenate, 3 pounds; water, 50 gallons-----	79.2
Lead arsenate, 4 pounds; water, 50 gallons-----	91.8
Lead arsenate dust-----	81.1
Slaked lime, 4 pounds; water, 50 gallons-----	61.7
Check, water only-----	39.5

This indicated that it was the spray deposits remaining on the foliage which caused the beetles to leave.

NUMBER OF BEETLES ALIGHTING ON AND LEAVING SPRAYED AND UNSPRAYED FOLIAGE

The number of beetles which alighted on and which left a sprayed tree, as compared with the number which alighted on and which left an unsprayed tree, was determined by two experiments conducted in 1923. Two persons were assigned to a tree sprayed with lead arsenate at the rate of 4 pounds to 50 gallons of water, and two were assigned to the unsprayed tree. All beetles were shaken from the trees at the beginning of each period of observation and at the end of periods varying between one and two hours. The foliage was given but one application of spray. With the aid of mechanical counters one person recorded the number of beetles alighting on the tree and the other recorded the number leaving.

The results of this experiment are shown in Table 4. In the experiment in which the trees were surrounded by sprayed trees, 87.5 per cent of the beetles alighting on the sprayed tree left, while 71.3 per cent of those alighting on the unsprayed tree left. In the experiment in which the trees were surrounded by unsprayed trees, 76.3 per cent of the beetles alighting on the sprayed tree left, while 68.1 per cent of those alighting on the unsprayed tree left. The percentage for the unsprayed tree may be somewhat inaccurate in both experiments, because the beetles at times literally swarmed about the trees, making it practically impossible to get a record of every individual which alighted on or left the unsprayed foliage. The data indicate, however, that a slightly larger percentage of beetles leave sprayed trees than leave unsprayed trees, and that, although many do alight on sprayed trees, they leave before a mass of beetles accumulates.

TABLE 4.—*Number of Japanese beetles alighting on and leaving sprayed and unsprayed foliage, 1923*

ALL TREES SURROUNDED ON THREE SIDES BY SPRAYED TREES

Time after spraying	Time of day	Length of observation period	Sprayed foliage		Unsprayed foliage	
			Beetles arriving	Beetles leaving	Beetles arriving	Beetles leaving
Hours		Hours	Number	Number	Number	Number
(1)	10.15 to 11.30 a. m.-----	1½	31	26	42	33
3	1.15 to 3 p. m.-----	2¾	7	4	10	6
75	10.15 to 11.30 a. m.-----	1½	33	28	58	47
78	1.15 to 3 p. m.-----	2¾	12	12	12	6
216	10.15 to 11.30 a. m.-----	1½	14	11	30	21
219	1.15 to 3 p. m.-----	2¾	11	8	9	6
240	10.15 to 11.30 a. m.-----	1½	13	12	22	14
243	1.15 to 3 p. m.-----	2¾	11	10	19	17
288	10.15 to 11.30 a. m.-----	1½	51	48	61	53
291	1.15 to 3 p. m.-----	2¾	6	5	16	13
312	10.15 to 11.30 a. m.-----	1½	31	29	34	18
315	1.15 to 3 p. m.-----	2¾	10	6	2	0
384	10.15 to 11.30 a. m.-----	1½	12	8	35	21
387	1.15 to 3 p. m.-----	2¾	15	15	17	9
408	10.15 to 11.30 a. m.-----	1½	64	61	39	27
411	1.15 to 3 p. m.-----	2¾	30	24	23	15
Total-----			351	307	429	306
Per cent of beetles leaving based on number of beetles arriving-----			87.5		71.3	

ALL TREES SURROUNDED ON THREE SIDES BY UNSPRAYED TREES

(1)						
52	1.30 to 3 p. m.-----	1½	336	232	419	74
96	1.25 to 3.25 p. m.-----	2	86	73	374	303
122	1.25 to 3.25 p. m.-----	2	268	231	2,205	920
126	8.25 to 10.25 a. m.-----	2	159	149	329	299
180	1.30 to 3 p. m.-----	1½	30	21	697	735
240	10.25 to 11.25 a. m.-----	1	64	27	134	203
241	10 a. m. to 12 m.-----	2	101	55	271	291
241	1.30 to 3.30 p. m.-----	2	56	51	444	495
Total-----			1,100	839	4,873	3,320
Per cent of beetles leaving based on number of beetles arriving-----			76.3		68.1	

¹ Immediately after spraying.

TOXIC EFFECTS OF CERTAIN ARSENATE SPRAYS

MORTALITY OF BEETLES COLLECTED FROM SPRAYED AND UNSPRAYED FOLIAGE

To determine the percentage of beetle mortality on a tree sprayed with lead arsenate 3 pounds, wheat flour 2 pounds, and water 50 gallons, beetles were captured in butterfly nets as they left the sprayed foliage 1, 2, 2½, 3, 4, 48, and 72 hours after the spray was applied, and were placed in a small wire cage, where they were supplied with smartweed for 48 hours. At the end of this 48-hour period the number that had died within the cage was recorded. As a control, beetles were collected from unsprayed smartweed plants to determine their normal mortality. The results of this experiment, which was conducted in 1923, are shown in Table 5, and summarized in Table 6.

TABLE 7.—Dead Japanese beetles collected below sprayed trees

Date sprayed	Material used per 50 gallons of water	Time between spraying and collection		Dead beetles collected
		Hours	Number	
1923 June 21	Lead arsenate, 4 pounds; flour, 2 pounds	16	275	
		22	96	
		48	219	
		72	112	
		96	36	
		108	87	
		120	23	
		144	23	
		6	345	
		25	184	
22	do	49	95	
		73	84	
		97	43	
		168	54	
		192	41	
		216	50	
		240	19	
		51	65	
		56	13	
		80	56	
26	Lead arsenate, 3 pounds; flour, 2 pounds	104	15	
		128	11	
		24	5	
		48	8	
		72	10	
		96	0	
		120	7	
		144	15	
		168	18	
		192	19	
27	do	216	22	
		240	15	
		264	10	
		288	19	
		312	5	
		24	3	
		48	10	
		72	20	
		96	18	
		120	23	
27	Calcium arsenate, 3 pounds; flour, 2 pounds	144	50	
		168	62	
		192	42	
		216	41	
		240	30	
		264	3	
		288	6	
		312	4	

Many of the beetles taken during the first collection were found to be spotted with spray residue, showing that some of those that were on the tree at the time it was sprayed had remained.

The results indicate that one spraying is effective in killing beetles over a period of several days, and that a certain number feed sufficiently upon the sprayed foliage to obtain a lethal dose of poison.

REPELLENT EFFECTS OF VARIOUS TOXIC AND NONTOXIC MATERIALS

NUMBER OF BEETLES FOUND ON SPRAYED AND UNSPRAYED FOLIAGE

Because of the success obtained with slaked lime in repelling beetles, as shown in the previous experiment, further experiments were conducted with this and with other nontoxic materials and with some toxic materials. The materials tested in the field for repellent effect upon the beetle included acid lead arsenate, acid lead arsenate colored black, slaked lime, chalk, barytes, china clay, Paris green, copper arsenate, acid lead arsenate colored green, basic lead arsenate,

magnesium arsenate, and calcium arsenate. Foliage sprayed with water was used as a check.

The following method was used: Two uniform peach or sassafras trees were selected, small enough to permit close observation, and located where beetles were abundant. Each tree was sprayed thoroughly, and all beetles were removed by shaking the tree vigorously after the spray had dried. The beetles on each tree were counted by six observers at the end of 15-minute intervals, and the number that appears in the totals is the average of the six counts. The numbers arriving, leaving, and hovering without alighting during each 15-minute period were also noted, and recorded by means of mechanical counters. Three observers were assigned to each tree, one to count the incoming beetles, one to count the beetles leaving, and a third to count those hovering without alighting. At the end of each 15-minute period, as soon as the beetles on the trees had been counted, both trees were shaken to remove those beetles that were left, thus obviating the possibility that some trees might be favored because of an accumulation of beetles. As soon as the beetles had been shaken from the tree, counts were again made, and one count followed another during that part of the day in which the beetles were most active, usually from 10 a. m. to 4.30 p. m. Counts were not made when weather conditions were unfavorable for movement of the beetles.

Tables 7 and 8 include data on the effect of a number of materials, some of which were used simultaneously. The comparative repellent value of these materials is indicated when the results from each are compared with those from the checks, which were sprayed with water. It was not possible to test all the materials simultaneously, as this would have required more men and more equipment than were available. Care was taken, however, to have conditions as nearly as possible the same in all tests, although there was some unavoidable variation in size of trees, density of infestation, etc. The amount of beetle injury to the foliage varied somewhat and prevented a uniform coating with the spray. The number of beetles found on foliage sprayed with various materials and on unsprayed foliage over a period of two or more days in 1924 is presented in Table 8. The efficiency of the material, which is expressed as a percentage, was found by subtracting the number of beetles on the treated tree from the number on the untreated tree and dividing the difference by the number on the untreated tree.

TABLE 8.—*Repellent effect upon Japanese beetles of various toxic and nontoxic materials,¹ 1924*

Date	Duration of experiment	Lead arsenate, 3 pounds		Slaked lime, 4 pounds		Barytes, 3 pounds		Chalk, 3 pounds		Paris green, 9 pounds		China clay, 3 pounds		Green lead arsenate, 3 pounds		Check
		Beetles on tree	Repellency	Beetles on tree	Repellency	Beetles on tree	Repellency	Beetles on tree	Repellency ²	Beetles on tree	Repellency ²	Beetles on tree	Repellency	Beetles on tree	Repellency	
	Days	No.	P. ct.	No.	P. ct.	No.	P. ct.	No.	P. ct.	No.	P. ct.	No.	P. ct.	No.	P. ct.	No.
July 10.....	10	1,931	90.4	12,166	39.7	—	—	—	—	—	—	—	—	—	—	20,190
July 15.....	12	1,008	91.9	1,762	85.8	—	—	—	—	—	—	—	—	—	—	12,424
July 21.....	6	2,247	66.1	—	—	3,584	45.9	—	—	—	—	—	—	—	—	6,624
July 23.....	4	644	67.2	—	—	983	49.9	—	—	—	—	—	—	—	—	1,963
July 30.....	5	—	—	—	—	333	65.3	291	69.7	1,722	+79.4	38	96.0	—	—	960
Aug. 2.....	3	8	94.8	33	78.4	—	—	—	—	1,019	+566.0	—	—	—	—	53
Aug. 6.....	2	25	86.0	—	—	—	—	24	86.6	386	+115.6	—	—	89	50.3	179
Aug. 7.....	2	33	64.5	—	—	—	—	—	—	—	—	—	—	—	—	93
Aug. 8.....	2	—	—	—	—	—	—	18	+125.0	49	+512.5	—	—	—	—	8
Average ³	—	—	85.8	—	57.4	—	48.7	—	+71.0	—	+144.3	—	96.0	—	50.3	—

¹ Quantities given were added to 50 gallons of water.² Plus sign indicates attraction.³ Based on totals.

In every experiment conducted in 1924 in which lead arsenate slaked lime, barytes, china clay, or lead arsenate colored green was used, beetles were repelled. The efficiency of the materials varied with the length of time they were retained on the foliage. Slaked lime, for instance, repelled almost as many beetles as did lead arsenate during a day or two following the treatment, but after this period the repellent action slowly decreased, because slaked lime did not stick to the foliage so well as lead arsenate. It appears that lead arsenate and the other materials used have a repellent effect upon the beetle which does not depend altogether upon their toxic properties.

In 1925 experiments were continued with the materials that had proved to be repellent in 1924, and experiments were begun with copper arsenate, basic lead arsenate, and calcium arsenate. The results are shown in Table 9.

TABLE 9.—*Repellent effect upon Japanese beetles of various toxic and nontoxic materials,¹ 1925*

Date	Duration of experiment	Lead arsenate, 3 pounds		Slaked lime, 4 pounds		Barytes, 3 pounds		Chalk, 3 pounds		Copper arsenate, 3 pounds	
		Beetles on tree	Repellency	Beetles on tree	Repellency	Beetles on tree	Repellency	Beetles on tree	Repellency	Beetles on tree	Repellency
	Days	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
June 26.....	4	809	58.2	321	83.5	—	—	—	—	—	—
June 30.....	6	1,103	60.9	—	—	—	—	—	—	—	—
July 3.....	4	424	75.3	—	—	—	—	—	—	—	—
July 7.....	2	248	51.2	447	12.0	—	—	—	—	—	—
Do.....	1	—	—	—	—	—	—	77	77.7	—	—
July 16.....	1	341	42.2	—	—	—	—	—	—	—	—
July 20.....	4	24	85.6	—	—	153	7.8	—	—	43	74.1
July 28.....	2	294	72.9	—	—	761	29.8	—	—	601	44.6
July 29.....	11	224	89.9	6	99.7	—	—	—	—	—	—
Aug. 3.....	7	306	74.6	—	—	—	—	—	—	614	49.0
Average ²	—	—	69.2	—	83.4	—	26.9	—	77.7	—	48.7

¹ Quantities given were added to 50 gallons of water.² Based on totals.

TABLE 9—*Repellent effect upon Japanese beetles of various toxic and nontoxic materials, 1925—Continued*

Date	Duration of experiment	China clay, 3 pounds		Green lead arsenate, 3 pounds		Basic lead arsenate, 6 pounds		Calcium arsenate, 3 pounds		Check
		Beetles on tree	Repellency	Beetles on tree	Repellency	Beetles on tree	Repellency	Beetles on tree	Repellency	Beetles on tree
	Days	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number
June 26.....	4	743	61.7							1,940
June 30.....	6					1,161	58.9			2,823
July 3.....	4									1,718
July 7.....	2	230	54.7							508
Do.....	1					80	76.9			346
July 16.....	1			425	28.0					590
July 20.....	4							31	81.3	166
July 28.....	2							328	69.7	1,084
July 29.....	11	27	98.8							2,211
Aug. 3.....	7							346	71.3	1,204
Average ¹			78.5		28.0		60.8		71.3	

¹ Based on totals.

Beetles were repelled by all materials tested, both toxic and non-toxic, in the experiments conducted during 1925.

NUMBER OF BEETLES ALIGHTING ON AND LEAVING SPRAYED AND UNSPRAYED FOLIAGE

Another method used to determine the repellency to the beetle of the materials listed in Tables 7 and 8 was to compare the number of beetles leaving the sprayed trees with the number of those alighting on them. The percentage of repellency was found by dividing the number of beetles leaving a tree by the number alighting on it, and as the same method was used for the check and for the sprayed trees, a direct comparison could be made. The results obtained in 1924 are given in Table 10, and those obtained in 1925 are given in Table 11.

TABLE 10.—*Number of Japanese beetles alighting on and leaving sprayed ¹ and unsprayed foliage, 1924*

Date	Duration of experiment	Lead arsenate, 3 pounds			Slaked lime, 4 pounds			Barytes, 3 pounds			Chalk, 3 pounds		
		Beetles alighting	Beetles leaving		Beetles alighting	Beetles leaving		Beetles alighting	Beetles leaving		Beetles alighting	Beetles leaving	
	Days	Number	Number	Per cent	Number	Number	Per cent	Number	Number	Per cent	Number	Number	Per cent
July 10.....	10	1,081	804	74.4	2,485	1,098	44.2						
July 15.....	12	843	564	66.9	609	355	58.3						
July 21.....	6	1,429	907	63.5				1,398	579	41.4			
July 23.....	4	1,405	1,087	77.4				1,213	603	49.7			
July 30.....	5							247	119	48.2	195	90	46.2
Aug. 2.....	3	20	14	70.0	16	10	62.5						
Aug. 6.....	2	53	38	71.7							57	34	59.6
Aug. 7.....	2	71	49	69.0									
Aug. 8.....	2										11	8	72.7
Average ¹				70.7			47.0			45.5			50.2

¹ The quantities of the different materials given were added to 50 gallons of water.² Figures represent the percentages of total numbers of beetles leaving, based on the total numbers alighting.

TABLE 10.—*Number of Japanese beetles alighting on and leaving sprayed and unsprayed foliage, 1924—Continued*

Date	Duration of experiment	Copper arsenate, 3 pounds			Paris green, 9 pounds			Green lead arsenate, 3 pounds			Check		
		Beetles alighting			Beetles alighting			Beetles alighting			Beetles alighting		
		Number	Number	Per cent	Number	Number	Per cent	Number	Number	Per cent	Number	Number	Per cent
July 10	10										5,369	977	18.2
July 15	12										2,468	972	39.4
July 21	6										2,477	952	38.4
July 23	4										1,641	989	60.3
July 30	5	667	258	38.6	943	309	32.8				592	303	51.2
Aug. 2	3				578	200	34.6				147	102	69.4
Aug. 6	2				346	105	30.3	125	73	58.4	105	50	47.6
Aug. 7	2										92	38	41.3
Aug. 8	2				86	45	52.3				58	43	74.1
Average ¹				38.6			33.7			58.4			34.2

¹ Figures represent the percentages of total numbers of beetles leaving, based on the total numbers alighting.

TABLE 11.—*Number of Japanese beetles alighting on and leaving sprayed ¹ and unsprayed foliage, 1925*

Date	Duration of experiment	Acid lead arsenate, 3 pounds			Slaked lime, 4 pounds			Barytes, 3 pounds			Chalk, 3 pounds		
		Beetles alighting			Beetles alighting			Beetles alighting			Beetles alighting		
		Number	Number	Per cent	Number	Number	Per cent	Number	Number	Per cent	Number	Number	Per cent
June 26	4	745	399	53.5	376	137	36.4						
June 30	6	672	279	41.5									
July 3	4				47	26	55.3						
July 7	2	592	286	48.3									
Do	1				458	240	52.4						
July 16	1	73	33	45.2							229	83	36.2
July 20	4	143	85	59.4				164	108	65.9			
July 28	2	327	131	40.1				522	204	39.1			
Average ²				47.5			45.7			45.5			36.2

Date	Duration of experiment	Copper arsenate, 3 pounds			China clay, 3 pounds			Basic lead arsenate, 6 pounds			Green lead arsenate, 3 pounds		
		Beetles alighting			Beetles alighting			Beetles alighting			Beetles alighting		
		Number	Number	Per cent	Number	Number	Per cent	Number	Number	Per cent	Number	Number	Per cent
June 26	4				780	308	39.5						
June 30	6							512	215	42.0			
July 3	4												
July 7	2												
Do	1				503	283	56.3						
July 16	1							286	216	75.5			
July 20	4	252	191	75.8									
July 28	2	572	221	38.6							493	352	71.4
Average ¹				50.0			46.1			54.0			71.4

¹ The quantities of the different materials given were added to 50 gallons of water.

² Figures represent the percentages of total numbers of beetles leaving, based on the total numbers alighting.

TABLE 11.—*Number of Japanese beetles alighting on and leaving sprayed and unsprayed foliage, 1925—Continued*

Date	Duration of experiment	Magnesium arsenate, 3 pounds			Calcium arsenate, 3 pounds			Check		
		Beetles alighting	Beetles leaving		Beetles alighting	Beetles leaving		Beetles alighting	Beetles leaving	
	Days	Number	Number	Per cent	Number	Number	Per cent	Number	Number	Per cent
June 26	4							1,667	355	21.3
June 30	6							709	372	52.5
July 3	4							387	271	70.0
July 7	2							458	240	52.4
Do	1							553	308	55.7
July 16	1							72	27	37.5
July 20	4	170	110	64.7	221	183	82.8	236	165	69.9
July 28	2	500	227	45.4	425	153	36.0	937	233	24.9
Average ²				50.3			52.0			39.3

² Figures represent the percentages of total numbers of beetles leaving, based on the total numbers alighting.

The results given in Tables 10 and 11 show that a larger percentage of the beetles which alighted left the treated trees than left the check trees in every case except those in which Paris green was used in 1924 and in which chalk was used in 1925. This indicates that the beetles were repelled by all the materials except Paris green and chalk after having alighted on the foliage.

NUMBER OF BEETLES HOVERING WITHOUT ALIGHTING ON SPRAYED AND UNSPRAYED FOLIAGE

Many beetles were observed to fly toward sprayed trees, to hover for a while without alighting, and then to fly away; others were observed to fly directly toward a tree, apparently with the intention of alighting, but suddenly to change their course when within 1 or 2 feet of the foliage, and to continue their flight without stopping. These beetles, which appear to be repelled from the sprayed foliage before coming into actual contact with it, are said to hover without alighting.

The results of observations on the number of beetles hovering without alighting and on those alighting on foliage sprayed with various materials, together with those for the unsprayed check, appear in Table 12. The trees were selected for uniformity of size and were in close proximity one to another in Harmer's late peach orchard.

The effect of the various sprays is shown in Tables 12 and 13. In Table 13 the percentage of beetles hovering without alighting is based in each case upon the total number of beetles which approached the tree—that is, the sum of those which hovered without alighting and those which alighted. The effectiveness of each spray may be seen by comparing the percentage hovering without alighting on the sprayed tree with the percentage hovering without alighting on the check during the same period of time. A study of the data in Table 12 shows that the materials fall, in the order of descending efficiency in repelling the beetles before alighting, as follows: Acid lead arsenate, barytes, slaked lime, chalk, green lead arsenate, and Paris green. It will be noted that in the case of Paris green the beetles were attracted instead of repelled. This attraction was probably due to the odor

of acetic acid which accompanies the material, as has been explained previously by the writer.⁴ It appeared, while conducting this experiment, that the proportion of beetles repelled before alighting varied directly with the degree of conspicuousness of the spray deposit on the foliage.

TABLE 12.—*Number of Japanese beetles hovering without alighting on sprayed¹ and unsprayed foliage*

Date	Duration of experiment	Acid lead arsenate, 3 pounds		Slaked lime, 4 pounds		Barytes, 3 pounds		Chalk, 3 pounds	
		Beetles hovering without alighting	Beetles approaching tree	Beetles hovering without alighting	Beetles approaching tree	Beetles hovering without alighting	Beetles approaching tree	Beetles hovering without alighting	Beetles approaching tree
1924	Days	Number	Number	Number	Number	Number	Number	Number	Number
July 10.....	10	625	1,706	546	3,031				
July 15.....	12	788	1,631	597	1,206				
July 21.....	6	847	2,276			672	2,025		
July 23.....	4	1,969	3,374			1,335	2,548		
July 30.....	5					144	391		
Aug. 2.....	3	355	375						
Aug. 6.....	2	226	279						
Aug. 7.....	2	258	3,290						
Aug. 8.....	2							93	104
Total.....		5,068	12,931	1,143	4,237	2,151	4,964	93	104

Date	Duration of experiment	Paris green, 9 pounds		Green lead arsenate, 3 pounds		Check	
		Beetles hovering without alighting	Beetles approaching tree	Beetles hovering without alighting	Beetles approaching tree	Beetles hovering without alighting	Beetles approaching tree
1924	Days	Number	Number	Number	Number	Number	Number
July 10.....	10					416	5,785
July 15.....	12					394	2,862
July 21.....	6					383	2,860
July 23.....	4					699	2,340
July 30.....	5	102	1,045			452	1,044
Aug. 2.....	3	388	966			331	478
Aug. 6.....	2	318	661	329	454	207	312
Aug. 7.....	2					87	179
Aug. 8.....	2					249	307
Total.....		808	2,672	329	454	3,218	16,167

¹ The quantities of the different materials given were added to 50 gallons of water.

TABLE 13.—*Effect of sprays^a in causing Japanese beetles to hover without alighting*

	Acid lead arsenate, 3 pounds	Slaked lime, 4 pounds	Barytes, 3 pounds	Chalk, 3 pounds	Paris green, 9 pounds	Green lead arsenate, 3 pounds
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Beetles hovering without alighting on sprayed trees.....	39.2	27.0	43.3	89.4	30.2	72.5
Beetles hovering without alighting on check during same period.....	17.0	9.4	24.6	81.1	54.0	66.3
Increase in beetles hovering without alighting due to repellent action of spray.....	22.2	17.6	18.7	8.3	-23.8	6.2

^a The quantities of the different materials given were added to 50 gallons of water.

⁴ VAN LEEUWEN, E. R. A PRELIMINARY NOTE ON THE ATTRACTIVENESS OF ACETIC ACID TO THE JAPANESE BEETLE. (Scientific note.) Jour. Econ. Ent. 19: 190. 1926.

EFFECTS OF SPRAYED AND UNSPRAYED FOLIAGE ON THE FEEDING OF INDIVIDUAL BEETLES

Observations were made during the seasons of 1923, 1924, and 1925 to determine if there were any distinct variations in the amount of feeding by beetles on foliage sprayed with a toxic material, on foliage sprayed with a nontoxic material, and on foliage that was not sprayed. The foliage used was sassafras, and the experiments were made under normal conditions in the field.

Small trees were selected, so that it would be possible to observe and record the amount of feeding from the time the beetle alighted on the foliage until it left. A large reading glass was used in making the observations in order not to disturb the beetle by approaching it too closely.

The quantity of each toxic material added to 50 gallons of water was as follows: Lead arsenate, 3 pounds; copper arsenite, 3 pounds; calcium arsenate, 3 pounds; magnesium arsenate, 3 pounds. The quantity of each nontoxic material added to 50 gallons of water was as follows: Slaked lime, 4 pounds; basic lead carbonate, 4 pounds; china clay, 3 pounds; barytes, 3 pounds; chalk, 4 pounds; New Jersey dry mix, 12½ pounds. The results are summarized in Table 14.

TABLE 14.—*Effects of sprayed and unsprayed foliage on the feeding of individual Japanese beetles*

Character of spray	Beetles observed	Beetles not feeding
	Number	Per cent
Toxic.....	275	54
Nontoxic.....	139	51
Check.....	164	63

These figures help to explain why the proportion of beetles killed after alighting on sprayed foliage is no greater. Whether the foliage is sprayed or not, many beetles leave without feeding, and although the toxicity of a spray is based on the proportion of beetles that die after having fed, its efficiency as a poison depends upon the proportion of beetles that actually do feed. It follows, therefore, that a spray which is relished by the beetles, and which will attract them and cause them to feed, will be most effective.

SUMMARY

The fact that fewer Japanese beetles accumulate on foliage sprayed with lead arsenate than on unsprayed foliage has led investigators to believe that this material is more repellent than toxic to the beetle. A study was therefore made of the movements of the Japanese beetle with relation to foliage on which there were spray deposits, with the object of determining why the beetle will not readily eat standard spray materials. This investigation included a study of the attractive influence of an accumulation of beetles, the repellent effects of lead arsenate and of other toxic and nontoxic materials sprayed on foliage, the toxic effects of certain materials sprayed on foliage, and the effects of spraying upon the feeding of individual beetles.

An accumulation of beetles upon a plant attracts other beetles that are flying about in the vicinity.

Many beetles are repelled before alighting on foliage sprayed with lead arsenate. The number of beetles alighting on the foliage of a plant sprayed with lead arsenate is less than the number alighting on a similar but unsprayed plant.

Most of the beetles leave foliage that has been sprayed with lead arsenate or with slaked lime within three hours. Some of the beetles on the tree fly off or drop off during the operation of spraying. A larger percentage of beetles leave foliage sprayed with lead arsenate than leave unsprayed foliage during a similar period of time; hence, there is never so great an accumulation of beetles on the sprayed foliage.

The highest mortality of beetles which had eaten foliage sprayed with 3 pounds of lead arsenate, 2 pounds of wheat flour, and 50 gallons of water occurred among those collected one hour after application of the spray, the range being from 42 to 64.6 per cent. Some of the beetles on the foliage at the time of spraying consume a fatal dose of poison. Certain poisonous sprays are effective for killing beetles during a period of several days.

The following materials used in sprays are repellent to the beetle: Lead arsenate, slaked lime, barytes, chalk, china clay, lead arsenate colored green, basic lead arsenate, and copper arsenate. Paris green attracts the beetle.

A larger percentage of beetles leave trees sprayed with lead arsenate, slaked lime, barytes, copper arsenate, lead arsenate colored green, china clay, basic lead arsenate, magnesium arsenate, or calcium arsenate than leave similar but unsprayed trees. Chalk was repellent in two experiments and attractive in one experiment made in 1924, and was repellent in one experiment made in 1925. Paris green, which was used only in the 1924 experiments, was slightly attractive.

A larger percentage of beetles hover without alighting on trees sprayed with lead arsenate, slaked lime, barytes, chalk, or lead arsenate colored green than about similar but unsprayed trees. A smaller percentage hover without alighting on trees sprayed with Paris green than upon similar but unsprayed trees.

Many beetles that come to sprayed or unsprayed foliage leave without feeding.

SUMMARY

The fact that fewer Japanese beetles accumulate on foliage sprayed with lead arsenate than on unsprayed foliage has led investigators to believe that this material is more repellent than toxic to the beetle. A study was therefore made of the movements of the Japanese beetle with relation to foliage on which there were spray deposits, with the object of determining why the beetle will not readily eat standard spray materials. The investigation included a study of the attractive influence of an accumulation of beetles, the repellent effects of lead arsenate and of other toxic and nontoxic materials sprayed on foliage, and the toxic effects of certain materials sprayed on foliage, and the effects of spraying upon the feeding of individual beetles.

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